

12. By touching different points of the wire with different reagents, the excitability of these portions are rendered unequal. Hence a resultant electromotive variation may be obtained by vibrating the wire as a whole. The current in the wire is from the less to the more excitable.

13. By this method, invisible traces of physico-chemical change in a wire may be detected.

14. Chemical reagents not only change the excitability but the quickness of response. Two points having two different rates of excitation will thus, under proper conditions, give rise to diphasic effects.

I take this opportunity to thank the Managers of the Royal Institution for the facilities offered me to carry on the investigation at the Davy-Faraday Laboratory.

“On the Effect of a Longitudinal Magnetic Field on the Internal Viscosity of Wires of Nickel and Iron, as shown by Change of the Rate of Subsidence of Torsional Oscillations.” By Professor ANDREW GRAY, F.R.S., and ALEXANDER WOOD, B.Sc., Houldsworth Research Student in the University of Glasgow. Received May 1,—Read May 15, 1902.

We can obtain information as to the nature of the magnetisation of magnetisable bodies only by testing the various hypotheses with reference to effects which it seems likely should, under these hypotheses, be produced on the physical properties of the substance. Thus, for example, the internal friction of the different parts of a solid must depend upon the size and mode of arrangement of these parts, and any alteration in their dimensions or relative arrangement ought in general to produce some change in the amount of the internal friction. Magnetisation of iron and other substances has with great probability been supposed to consist in a rearrangement and general alignment of the particles of the substance, already themselves elementary magnets, but so arranged in the unmagnetised metal as to be unproductive of any external magnetic field. It is not unusual to suppose that this unmagnetised state is one of what we may call complete absence of arrangement, and it is sometimes so represented in text-books on the subject of magnetism, where pictures are given of a perfectly confused distribution of elementary magnets, so completely mixed up as to have no preponderating magnetic moment in any one direction. Any such distribution, it is clear at once from the most elementary considerations, is impossible, as a large majority of the elementary magnets would otherwise have to remain in stable equilibrium in

unstable conditions of magnetic forces, a state of things which could only be brought about with the assistance of forces independent of magnetic action—forces which there is otherwise good reason to believe do not exist to anything like the degree which would be necessary. There are other reasons for believing that in the unmagnetised metal the elementary magnets have a perfectly orderly arrangement in closed chains, each of which may be composed of a large group of molecules of the substance. These molecules, when the substance is unmagnetised, form a closely coherent arrangement which is broken up into an entirely different collocation under the influence of an externally applied magnetic field. Thus if the wire of the unmagnetised material perform torsional oscillations, the relative motions of the parts of the material will naturally be affected by the internal forces existing between the parts, and by the arrangement of the parts in more or less distinct chains or groups. It is reasonable to suppose that the effect of magnetisation being to entirely alter these internal magnetic forces, and to break up and rearrange the groups of elementary magnets, will be also to alter considerably the internal friction shown by the material. With this idea in view, we have subjected wires of iron, nickel, and steel to longitudinal magnetising forces, while they were compelled to perform torsional oscillations round their axes, and have observed the rate of subsidence of these oscillations with magnetising forces of different values, the amounts of which will be found stated in curves illustrative of the results obtained. The effects of the fields were found to be considerable in amount and very curious in character. For example, in the case of iron, as the material was more intensely magnetised, the rate of subsidence of the oscillations continually diminished; on the other hand, with wires of nickel in the state in which they were received from the maker, the effect was to increase the rate of subsidence until a certain value of the magnetising force was reached, after which the rate of subsidence diminished with further increase of the magnetising force. These results were modified considerably by alteration in the state of the material, produced by drawing the wires through a draw-plate.

Since the completion of the experiments described in this paper, we have become aware of a paper by Mr. Herbert Tomlinson, on the subject of the effect of magnetisation on the internal viscosity of iron.* The results obtained by Mr. Tomlinson, show an increase of viscosity produced by a field of 35 units, which is contrary to the effects described below. But the extreme amplitude in Mr. Tomlinson's experiments was only 10° for a wire 1 metre long, as against 90° in our experiments; and as we have pointed out below, the effect seems to depend in an important way upon the amplitude, though

* 'Phil. Trans.,' A, vol. 179, 1888.

whether it changes sign in our specimens at very low amplitudes we are as yet unable to say.

It will be convenient to give here a short description of the apparatus, and then to state in detail the results obtained from the experiments made on the three substances referred to. The specimens were wires about 1 metre long, and about 1.3 mm. in diameter. The exact dimensions are given below where the particular specimens are referred to in the arrangement adopted. The wire is suspended vertically along the axis of a magnetising coil A (Diagram I). Across the upper end of the coil is placed a cross-piece of brass, to which the upper end of the wire is attached, while the coil itself is supported by the upper cross-bar of a Willis frame which stands on the laboratory

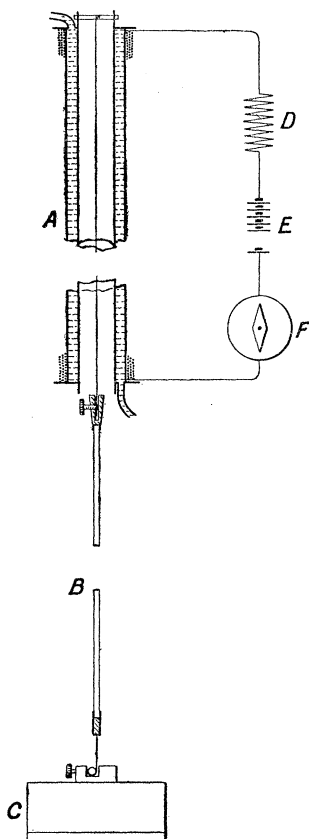


DIAGRAM I.

floor. About 3 or 4 cm. below the lower end of the coil, the wire is attached to a brass fitting cemented on to the upper end of a glass

rod B about a metre long and 5 mm. in diameter. To the lower end of this glass rod is rigidly fastened a cylindrical vibrator C. The axes of the wire, the glass rod, and the vibrator are as nearly as possible in one vertical straight line, and the three bodies are rigidly connected, so that if the vibrator is turned round its axis, no slipping takes place at the attachments. The wire and rod are thus subjected to twist, the amount of which is infinitesimal in the glass rod, which turns round its axis practically as a rigid body; so that the whole twist may be regarded as contained in the wire. This arrangement was adopted to keep the vibrator, which in all cases was of iron (being selected from a series of vibrators in the collection of apparatus), sufficiently remote from the coil to obviate the possibility of any action between the field of the coil and the moving vibrator, while the whole of the twisting and untwisting material was contained within the field. Round the lower edge of the vibrator is gummed a millimetre scale, which is read by a telescope, and the vibrations were always sufficiently slow to allow of the scale being read at the beginning and end of a semivibration, the difference between the two readings giving the amplitude. The coil consisted of 3080 turns of copper wire wound on a double core of brass tubing. This double core was made of two coaxial tubes, the outer $1\frac{1}{2}$ inches and the inner $\frac{1}{2}$ inch in diameter. The space between the tubes forms a water-jacket, through which a stream of water can be forced so as to shield the wire from the heating effect of the current in the coil. The current produced by the battery E, and adjusted by the resistance D, was measured by a Kelvin graded galvanometer F, and the field was calculated from the value $4\pi Cn$ for the intensity of the field produced by a current of C absolute units flowing in a coil of n turns per cm. of length.

Results for Nickel.—The wire used was obtained from Messrs. Johnson and Matthey, London, and was stated by them to contain only a very small percentage of impurity. Its diameter was 1.4 mm. The results of the experiments are shown in Diagram II. In the curves of that diagram the abscissæ, drawn from left to right, show amplitude of vibration in degrees; the ordinates, drawn downwards, represent the number of periods which have elapsed from the beginning of the set of observations. Thus we obtain the amplitude left after different numbers of oscillations have been performed, and are able to estimate from the curve the rate of subsidence. The ordinates may be taken as giving the time from the commencement of the set of observations, as it was found that the alteration of period produced by the imposition of the field was negligible, the actual periods being 7.21 seconds with a field of 132 C.G.S. and 7.17 seconds with no field. It will be seen that the effect of small fields is to greatly increase the rate of subsidence, but that at a field of about 160 C.G.S. the maximum effect of the field in increasing the rate of subsidence is produced: thus

Curves 1, 2, 3, 4 for fields up to 156 C.G.S., lie successively farther to the left in the diagram, while the Curves 5, 6, 7, 8 for fields from 187 to 360 C.G.S. lie in succession to the right of one another, showing in the first case a continual increase, and in the second a continual diminution in the rate of subsidence.

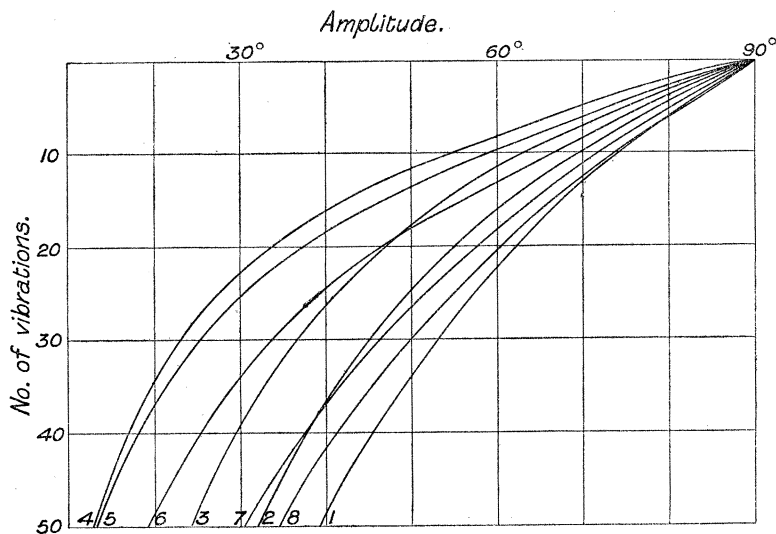


DIAGRAM II.

Curve.	Field.	Curve.	Field.
1	0 C.G.S.	5	187 C.G.S.
2	22 "	6	257 "
3	50 "	7	330 "
4	156 "	8	360 "

A curve for zero field was taken after these eight curves had been obtained, and it was found to agree closely with Curve 1 of the series shown in the diagram.

The logarithmic decrements were calculated for these curves and were found to diminish in each curve as the amplitude diminished. This diminution was about half the initial value of the logarithmic decrement for each of the first four curves, but then fell off until in curve 8 it was only $\frac{1}{5}$ of the value at the initial amplitude.

A series of experiments was made for the purpose of finding more precisely the value of that magnetising field which had maximum effect upon the rate of subsidence, and curves of subsidence were obtained for values of the field ranging from about 100 to about 200 C.G.S. The curves form a close series, and intersect one another in a way which it is rather difficult to disentangle, and which renders the critical value of the magnetic field in a sense indefinite. The crossing of the curves in the immediate neighbourhood of the critical

field was traced to a slight extent to small uncompensated effects of heating, but it is extremely unlikely that the crossing of the curves is due to this cause alone, as no doubt the effect of the magnetic field on the rate of subsidence depends upon the amplitude. Further experiments with more nearly perfect prevention of heating effects, are required to enable the dependence of the rate of subsidence on amplitude to clearly disclose itself. It may be mentioned, however, that the actual variations in temperature, as determined by observations of the temperature of the water issuing from the jacket, were very slight. For example, the temperatures at the end of each of nine successive experiments—the first and last of which were made with no current in the coil, and the others with currents from 2.56 to 6 amperes, varied from $6^{\circ}.5$ C. to 8° C.

It will be noticed that in Diagram II the shape of the curves undergoes change as the magnetic field is increased. This is most obvious near the critical value of the field, as shown by Curves 4 and 5. For Curve 4 the rate of subsidence at first is distinctly greater than in Curve 5, but as the amplitude diminishes the two curves approach one another, so that while, after ten, twenty, and thirty vibrations there is distinctly more amplitude left in Curve 5 than in Curve 4, there is practically the same amplitude left after fifty vibrations, the curves being then on the point of crossing. This effect seems, as we have said, to be, in part at least, due to the dependence of the magnetic effect on amplitude.

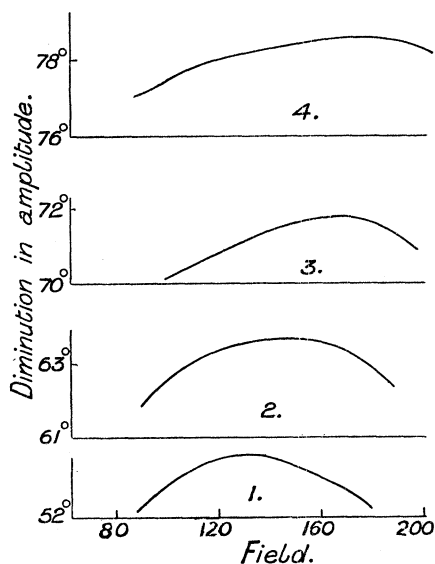


DIAGRAM III.

Diagram III brings out the point just alluded to more clearly. These curves show the effect of the different fields upon the amount of subsidence effected in the times corresponding to different numbers of vibrations and to different amplitudes. For example, Curve 1 gives a comparison of the subsidences (from an initial amplitude of 90°) effected in twenty vibrations under different fields varying from about 100 to 200 C.G.S. Curve 2 gives a comparison of the subsidences from the same initial amplitudes effected in thirty vibrations for the same range of field. Curves 3 and 4 show the subsidences for forty-five and seventy-five vibrations respectively in the same circumstances. It will be seen that the points of maximum of the curves trend to the right from Curve 1 to Curve 4—that is to say, the value of the field which produces maximum effect is greater the smaller the amplitude of the vibration to which it is applied.

Results for Iron.—Diagram IV shows curves of subsidence obtained for iron. Six curves are given showing the results for fields varying

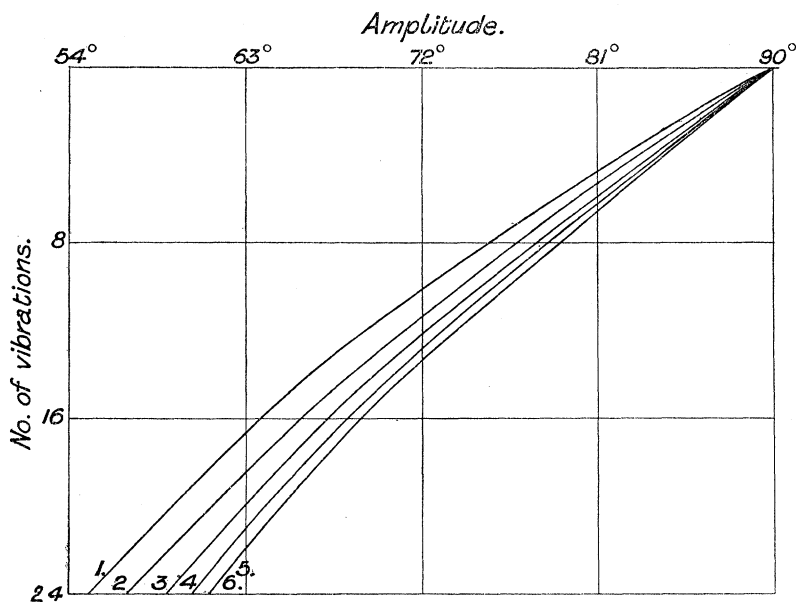


DIAGRAM IV.

Curve.	Field.	Curve.	Field.
1	0 C.G.S.	4	81 O.G.S.
2	22 "	5	170 "
3	44 "	6	229 "

from 0 to 230 C.G.S. It will be seen that the curves fall successively to the right of one another with the exception of 5 and 6, which are practically coincident. Experiments were also made for fields up to

about 400 C.G.S., but the curves obtained showed only a very slight tendency to move to the right, so slight that if they had been drawn they could not have been distinguished in the diagram from Curves 5 and 6. The same vibrator was used for the iron wire as had been used in the case of nickel, and the period of vibration was 5.27 seconds. For iron, then, we have the remarkable result that the effect of a magnetic field on the rate of subsidence of torsional oscillations is to diminish that rate, and by an amount diminishing with increasing field until a field of about 160 or 170 C.G.S. is reached, after which the effect of the field, however great, is practically constant. This is, of course, what one would expect in consequence of saturation of the iron, but it is a result very remarkably different from that obtained for nickel. The totally different behaviours in the two cases seem to point to an entirely different collocation of elementary magnets in the nickel and the iron, *i.e.*, perfectly distinct molecular constitution, consistent, however, in each case with magnetisability.

Results for Steel.—Diagram V shows three curves obtained for piano-forte steel wire. The same vibrator was employed as in the former

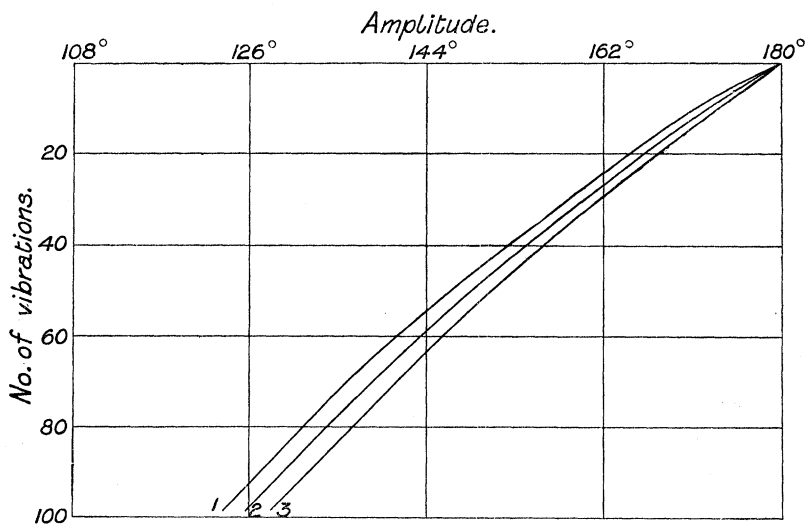


DIAGRAM V.

Curve.	Field.
1	0 C.G.S.
2	110 „
3	230 „

cases, and it gave with this wire a period of 16.81 seconds. The fields were respectively 0, 110, and 230 C.G.S., and it will be noticed that the results are very similar to those obtained for iron, except that the

effects are much smaller. The curves for higher fields moved continually to the right, and showed no tendency to become coincident.

In both iron and steel the logarithmic decrements, as the curves show, were much more nearly constant throughout each curve than was the case for nickel. In steel the decrement fell off rapidly at first, so that throughout the greater part of the curve it was nearly constant at a distinctly smaller value than at the beginning of the curve.

Experiments were also made with a view to ascertaining whether the change in the physical properties of the wires produced by drawing them through a draw-plate altered in any way the effects of magnetisation on the rate of subsidence. In the case of drawn nickel wire the most striking alteration was the disappearance of the reversal of the effect of magnetisation. The magnetisation increased slightly the rate of subsidence, and this increase continued quite regular to the highest values of the field obtainable (about 400 C.G.S.), no critical value of the field similar to that observed for the undrawn wire being obtained. In the case of drawn iron, on the other hand, the effect of magnetisation was to regularly diminish the rate of subsidence. The effect was thus similar to that obtained for the undrawn wire, the chief point of difference being that, in the case of the drawn wire, further increase of the field gave farther perceptible diminution in the rate of subsidence, so that there was not that approximation to constancy of effect of field, apparently depending on magnetic saturation, which was observed in the case of the undrawn wire. The drawing of the wires was found to result in a considerable increase of their rigidity.

As a check upon the experiments detailed above, a copper wire was substituted for the iron or nickel wire along the axis of the coil, and a field of 230 C.G.S. units was applied. No perceptible effect upon the rate of subsidence was found to be produced.

[*Note, added May 30, 1902.*—The effect of annealing the nickel wire which had been hardened by drawing has now been observed. The wire was heated to a bright red heat and then suddenly cooled by being plunged into water. It was found that the wire had returned to its former state, as all the features of the curves of Diagram II were again observed, with the difference that the curve of maximum rate of subsidence occurred with a field of only about half the former value. Experiments on the effect of annealing the iron wires are in progress, and show that the effect of annealing, by heating and slow cooling, is to annul the change produced by drawing.]